GENERAL ELECTRIC

RESEARCH AND DEVELOPMENT CENTER

SCHENECTADY, NEW YORK

PROGRESS REPORT

DESIGN CRITERIA FOR ZERO-LEAKAGE CONNECTORS FOR LAUNCH VEHICLES

Quarterly Progress Report No. 12

Contract NAS 8-4012

January 20, 1966

January 20, 1966

Reference: Contract NAS 8-4012

SUBJECT: Quarterly Report No. 12

Dear Mr. Wood:

1. Current Status of Technical Work

This report covers work on Contract NAS 8-4012 in the period from October 1, 1965, to December 31, 1965. Immediately following this letter you will find the revised time schedule which we discussed on December 8, 1965, when we met at your office. Those items which we regard as complete are marked as such. I have assumed that the work would be complete (final report submitted) on June 15, 1966, and we will apply for a contract extension within a few weeks.

As you know, Forrest Rathbun was the principal contributor on the task concerning analytical simulation of a seal interface as well as being project engineer for the entire job. Looking for a replacement on this task we have found that Mr. John K. Hawley's interests and background suit very well in this case, and accordingly he is now the principal technical contributor for this work. His biography is attached to this letter.

With regard to that task, Mr. Hawley and I have discussed it at some length and we feel that it is time that emphasis was placed on the calculation of flow through the interface. There is a discussion of our plans and reasoning concerning the interface problem in Section 2.0 of this report. Briefly, we plan to emphasize the calculation of flow because there is sufficient literature available to describe the geometry of two surfaces pressed in contact and we feel our present description (based on Abbot's bearing assumption) is in accordance with the content of the literature. It is our opinion that further emphasis on interface geometry without flow calculation would constitute an unbalanced study.

This report concerns the four tasks which have been named in past reports.

	TASK	PRINCIPAL CONTRIBUTOR
1.	Computerization of Handbook	R. E. Smith
2.	Interface Analysis	J. K. Hawley
3.	Advanced Leakage Requirements	J. P. Laniewski
4.	Superfinish Connector	B. Weichbrodt

The corresponding sections of this report give the details of their various work segments.

2. Finances

Expenditures and commitments through December 26, 1965 were 57 percent of the authorization for the contract. Man hours expended through December 26, 1965 were 5525.2.

Very truly yours,

J. A. Bain

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Mechanical Technology Laboratory
Mechanical Equipment Branch
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JAB/cn

TASK NO — DESIGN PROCEDURES FOR SEPARABLE CONNECTORS (NAS 8-4012)

DATE — Revised January 21, 1966

TASK ENGINEER — J. A. Bain

RESPONSIBLE SECTION — Mechanical Equipment Branch

Task	JAN. – DEC. (weeks 1–53)
1.1 Establishment of Flanged Connector Check Design	
1.2 Computerization of Flanged & Threaded Conn. Design Proced.	
Integral Flange	
First-Trial Sect	Complete
Analysis Sect	Complete
Revision Sect	
Assembly of Sections	
Separate Flange	
First-Trial Sect	
Analysis Sect	
Revision Sect	
Assembly of Sections	
Threaded Connector	
First-Trial Sect	Complete
Analysis Sect	
Revision Sect	
Assembly of Sections	
Documentation	
1.3 Standardization of Flanged Connector	
Selection of Family	
Design by Comp. Code	
Finalization & Drafting	

TASK NO – MATHEMATICAL MODEL OF INTERFACE SEALING PHENOMENON (NAS 8-4012)

DATE – Revised January 21, 1966

TASK ENGINEER– J. A. Bain

RESPONSIBLE SECTION– Mechanical Equipment Branch

Task	JAN. (1–5)	FEB. (6–9)	MARCH (10–13)	APRIL (14–18)	MAY (19–22)	JUNE (23–26)	JULY (27–31)	AUG. (32–35)	SEPT. (36–40)	OCT. (41–45)	NOV. (46–49)	DEC. (50–53)
2.1 Determination of Load-Area of Contact-Interface Gap Geometry							Complete					
2.2 Use of Periodic Nature of Surfaces in Program							Complete					
2.3 Utilization of Second Real Sealing Surface in Prog.							Complete					
2.4 Large Grid Size, Great Number of Height Increments in Program							Complete					
2.5 Determination of Flow Through a Given Gap Interface Geometry												
2.6 Finalization of Documentation												

RD-106 (12/65)

(NAS 8-4012)

TASK NO — LEAKAGE EXPERIMENTS TO BE CONDUCTED AT HIGH AND LOW TEMPERATURES TASK ENGINEER— J. A. Bain

DATE — Revised January 21, 1966 RESPONSIBLE SECTION— Mechanical Equipment Branch

Months: JAN. (weeks 1–5), FEB. (6–9), MARCH (10–13), APRIL (14–18), MAY (19–22), JUNE (23–26), JULY (27–31), AUG. (32–35), SEPT. (36–40), OCT. (41–45), NOV. (46–49), DEC. (50–53)

Task	Status (JULY, weeks 27–31)
3.1 Establish New Capabilities Demands on Experimental Apparatus	Complete
3.2 Design Apparatus, Temperature Equipment	Complete
3.3 Construction of All Apparatus	Complete
3.4 Selection of Tests	Complete
3.5 Checkout of Apparatus	Complete
3.6 Testing Programs	
3.7 Data Evaluation	

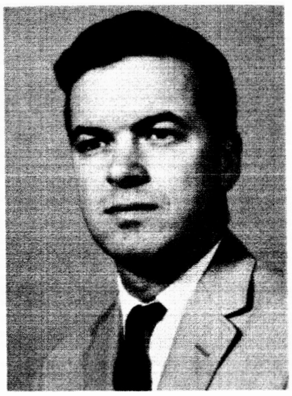
(NAS 8-4012)

TASK NO – DESIGN OF TUBE CONNECTOR INCORPORATING SUPERFINISH SEALING PRINCIPLE TASK ENGINEER – J. A. Bain

DATE – Revised January 21, 1966 RESPONSIBLE SECTION – Mechanical Equipment Branch

Task	JAN. (1–5)	FEB. (6–9)	MARCH (10–13)	APRIL (14–18)	MAY (19–22)	JUNE (23–26)	JULY (27–31)	AUG. (32–35)	SEPT. (36–40)	OCT. (41–45)	NOV. (46–49)	DEC. (50–53)
4.1 Selection of Finishing Technique, Seal Width, but Means of Protection							Complete					
4.2 Selection of Input for Design							Complete					
4.3 Design of Connectors												
4.3a Preliminary Analysis & Test of Sample Config. and Materials							Complete					
4.4 Manufacture of Two Prototypes												
4.5 Superfinishing of Two Prototypes												
4.6 Testing of Prototypes and Design Revision												
4.7 Manufacture Remaining Pilot Samples												
4.8 Superfinishing of Pilot Samples												
4.9 Testing of Pilot Samples												
Documentation												

RD-106 (12/65)



JOHN K. HAWLEY

MECHANICAL ENGINEER - MECHANICAL EQUIPMENT
ADVANCED TECHNOLOGY LABORATORIES

Mr. Hawley is engaged in analytical studies in the area of applied mechanics, including the development of digital computer solutions of three-dimensional stress analysis problems.

He came to the Advanced Technology Laboratories from the Department of Mechanical Engineering, Swarthmore College, where he was an instructor in fluid mechanics and elasticity, and in matrix algebra and FORTRAN programming. In earlier work - as a member of the Scientific Staff of the Technical Research Group, Incorporated, of Syosset, New York - he carried out theoretical and analog computer studies of ship hydrodynamics. He has also worked on instrumentation and new machining methods for jet engines and rocket cases, for the Curtiss-Wright Corporation, and made an experimental study of failure mechanisms around tunnels at Rensselaer Polytechnic Institute under contract to the MITRE Corporation.

Mr. Hawley received a BSME at Swarthmore College in 1958, and an MS in engineering mechanics at Columbia University in 1960. He is at present engaged in thesis research on fracture mechanics at Rensselaer Polytechnic Institute, where he has completed all other graduate work toward his PhD.

He received a Foundation Award from the Scott Paper Company, where he carried out fundamental studies in paper formation, and twice received Foundation Fellowships from the U. S. Rubber Company.

Mr. Hawley is an associate member of ASME and a member of Sigma Tau and Sigma Xi honor societies. He has written published articles and technical reports relating to his work.

TABLE OF CONTENTS

1. Design Procedure for Separable Connectors

1.1 Establishment of Flanged Connector Check Designs

Work on the four check designs chosen by NASA has been halted temporarily because the methods being programmed are not applicable where a pressure energized seal is to be used.

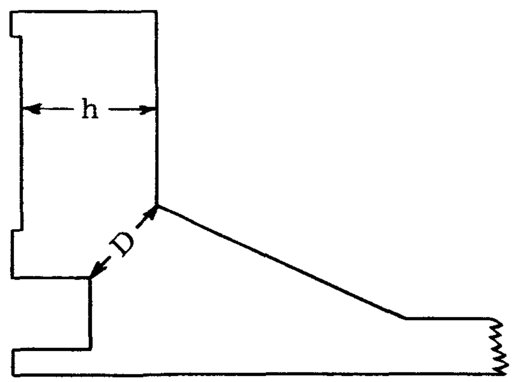
This matter was discussed with NASA personnel on December 8, 1965, and two items were suggested for further investigation.

Item 1) The amount of work necessary to include pressure energized seals in a computer program similar to those being written under this contract.

Some discussions on this subject have been held with General Electric people, but no definite conclusions have been reached at this time.

Item 2) A means of preventing the inadvertent use of the present program with pressure energized seals should be established.

One method of doing this is to make a check within the program, of the distance, D, between the corner of the gasket cut-out and the hub-flange intersection. If this distance is less than 0.9 of the flange thickness, h, then print an error message and stop the problem. In most cases, the reason the cut-out is large will be because a self-energizing seal is being used, but no matter what the reason, when the cut-out is overly large the program will not proceed.



1.2 Computer Programs for Flanged and Threaded Connectors

1.2.1 Computer Program for Flanged Connector Design

All of the subroutines pertaining to the analysis of integral flanges have been written and checked out. The completion of this portion of the program now allows all the forces, moments, displacements and stresses to be calculated for an integral flange connector of known dimensions, for a maximum of ten different operating conditions.

The subroutine which establishes the initial connector dimensions from the material properties and maximum operating conditions is called DESIGN. This subroutine has been written for both integral and loose flange connectors, but has only been checked out for the integral type at this time.

Tables for open end wrenches, socket wrenches and internal wrenches are included such that the user may indicate the type of wrenching to be employed.

The five subroutines which apply to the stress analysis of the loose flange connector have been written and compiled. Debugging of three of these subroutines, LOOSE, INIT 3, and FORCE 3, which deal with the loose flange without contact, has been started but is not complete.

Some initial work on the subroutine REVISE as it may apply to both loose and integral flange connectors has been done to establish the basic ground rules. These ground rules concern which dimensions are altered and by what amount, to bring all the stresses, deformations and gasket loads to acceptable values.

1.2.2 Computer Program for Threaded Connector Design

The initial connector dimensions are established as a function of input quantities and various tabular data pertaining to thread sizes, wrench sizes and other machinery data. This subroutine has been written and completely checked out during this reporting period.

The subroutine to evaluate the constants for the shell equations has been written and completely checked out. This subroutine is used repeatedly in the subsequent evaluation of the coefficients of the simultaneous equations for the spring constant of the nut and also for the calculation of the load on the seal.

A subroutine to calculate the coefficients of the simultaneous equations necessary to find the spring constant of the nut has also been written and checked out.

The coding of the coefficients (C35 through C104 in the handbook) of the simultaneous equations to solve for the forces, moments and displacements in the flange and union is completed, and debugging is in process.

All the work referred to above (except initial connector dimensions) concerns the stress analysis section of the program. Work has not yet started on the section of the program which revises dimensions for iteration.

The next step will be the programming of the stress equations (S_1 through S_{14} in the handbook).

1.3 Standardization of Selected Flanged Connectors

No work was done on this item during the reporting period. As agreed upon at the December 8, 1965 meeting, this work will start upon completion of the entire integral flange portion of the program.

2. Mathematical Model of Interface Sealing Phenomenon

2.1 Introduction

Since the subject of the contact of solid surfaces was one of particular interest to Forrest Rathbun, and an area in which he had done significant independent work, it has been necessary to review the objectives of this task and decide what is now the best course for their accomplishment.

In short, the goal of this task is to establish a means of estimating the reliability of a surface contact seal as determined by materials, dimensions, and loading. More specifically, the goal is to be able to understand the relation of design parameters and leakage probability so that the designer can hold that probability to within established limits. The basic procedure is as follows:

a) Generate a population of realistic mathematical models of seal surfaces.

b) Mating pairs of these surfaces, determine the true area of contact and the geometry of its complement, the region of finite separation.

c) Calculate leakage flow as related to the contained fluid and the pressure differential across the seal.

d) From a series of such calculations find the probability distribution function relating design parameters to the probability that leakage will not exceed any given rate.

In the phase of the work reported in the last quarterly report (No. 11, October 15, 1965), the mathematical techniques for implementing a) and b) had been worked out and were in operation on the G. E. 625 digital computer. In the past quarter representatives of the Burndy Corporation of Norwalk, Connecticut, have demonstrated, on a sample gasket supplied by General Electric, their capability of making exceptionally good Talysurf traces which are automatically recorded on punched cards. This data, for a selection of seal surfaces, should be very useful in evaluating and improving the physical accuracy of the mathematical surface models.

Existing literature on the relation of contact surface geometry to loading is being studied, and it appears that there is sufficient information available to make it unnecessary to engage in a theoretical or experimental study of this phenomenon. This and other details of the work remaining to be done are discussed more fully below.

2.2 Physical Accuracy of the Mathematical Surface Model

The results obtainable from the Burndy Corporation "topograph" should be of considerable use to us in obtaining a very realistic model of seal surfaces. Briefly, their technique permits sampling a surface at 1.7 micron (430 microinches) spacing, in parallel traverses at equal spacings of 3.4 microns, using three decimal digits per reading. A digital voltmeter connected to the Talysurf provides a digitized paper tape record which is then converted to punch cards. This information will not be of direct use to us in the work presently planned, but the demonstration of Burndy's techniques has important implications for any future studies which may take place.

The scientists in the Burndy Research Division have contributed and have indicated a willingness to continue to contribute valuable insights into many aspects of surfaces and their contact, based on considerable experience in this area. The Burndy Corporation manufactures electrical connectors, and are doing considerable research on phenomena in which we have a common interest, including leakage through an interface, which they are concerned with from the standpoint of contact corrosion. Their Director of Research, Dr. J.B.P. Williamson, and Dr. J.A. Greenwood, both of whom visited us to discuss their method and results are from the laboratory of Bowden and Taber at Cambridge, England where much of the most important work on surface phenomena has been carried out. To date Burndy's work has been done for us on an accommodation basis. We feel we have developed an excellent contact which we may be able to rely on more formally in the future.

2.3 Actual Area of Contact Between Real Surfaces

This topic has been the object of considerable research, and much literature exists which provides a guide to the establishment of a realistic computer model of surface geometry during loading, and the load-deformation relationships. It appears that a very simple model will yield results in substantial agreement with present concepts of solid contact.

One aspect of the surface deformation study which will require some investigation is interface sealing for loading subsequent to one or more disassemblies. If a surface which has undergone plastic deformation of asperities in a previous loading is mated with one of comparable or greater hardness (which is quite likely to occur when there is no gasket), the load to effect sealing will probably be greater, due to a reduced compliance of the surfaces. Thus, one is faced with the possibility of seal load being dependent on the histories of the mating surfaces.

2.4 Leakage Flow Calculations

Results so far obtained from the digital computer simulation of the mating of surfaces indicate a rather high (50 to 70 percent) area of real contact before there are no leak paths. For real surfaces, this would require a load of roughly 1.5 to 4 times the apparent yield load of the surface. It is thus important to obtain some estimate of the leakage flow rate associated with one or a network of leak paths to evaluate the seal reliability in a more realistic manner than the "go, no-go" criterion of searching for a leak path.

Leakage flow depends primarily on the minimum dimension of a leak path. There are two possible flow regimes of interest, laminar (viscous) and molecular, the type of flow in a particular case being determined by the magnitude of the governing dimension. In molecular flow (when the minimum dimension is on the order of the mean free path of the fluid) leakage is proportional to the ratio of the pressure differential; in laminar flow the leakage depends on the ratio squared. In a real situation there would generally be flow of both types in parallel and in series in the tortuous leak paths from inner to outer surface. To determine the flow rate through such a network, assuming the leak paths had been found by the computer, would be a very complicated procedure. L. G. Gitzendanner has, in a previous reporting period, worked out roughly a procedure for this solution; an estimate of the man and machine hours to implement the solution indicates that it would be likely to exceed the scope of the contract. It is intended, however, to give further consideration to methods of leak flow calculation and to formulate and apply a method which will give an accurate estimate of the flow rate, at lower cost than the rather elaborate network calculations previously envisioned.

Specifically, it seems that a statistical method would be consistent with the rest of the model. A possibility that will be explored is to utilize the statistical data obtained for a population of interfaces with leak path networks in a flow calculation for a randomly porous medium. This subject has received considerable study and techniques exist, already computerized, for flow calculation.

Another possiblity that will be considered is the application of Monte Carlo techniques, as in the estimates of percolation probabilities, for which computer programs also exist. (Broadbent and Hammersley; "Percolation Processes, Crystals and Mazes"; Proc. Cambr. Phil. Soc.; 1957.)

The primary object of this part of the seal interface study will be an accurate estimate of leakage flow, using the most direct and economical method that can be formulated. This will yield flow rates for particular interface geometries, the last link in the seal reliability analysis.

2.5 Parametric Evaluation of Seal Reliability

The ultimate goal to which the seal interface study leads is to be able to predict the leakage probability distribution function as it depends on design variables. Knowing the interface gap geometry, in the form of a random function, for a particular choice of materials, seal dimensions and load, the flow calculation will determine whether the total seal is acceptable. Alternatively, one might determine the load necessary to make a particular seal leak-tight. It is our feeling that all phases of the procedure outlined in 2.1 should be studied to some degree. A great deal of emphasis has been placed on the determination of interface geometry, and we now propose to place the emphasis primarily on flow calculation with a lesser emphasis on load-displacement relations.

3. Advanced Leakage Experiments

3.1 Introduction

Efforts during this reporting period were concentrated toward the completion of the proposed test program outlined in the previous quarterly report (October 15, 1965). Table 3.1 of that report was a description of the various seal systems to be tested and the range of temperatures involved. Tests number one (1) through fifteen (15) and number seventeen (17) have been accomplished to date. The data for tests 1, 2, 4, 5, 6, 7, 10, 11, 13, and 14 have been reduced; the results of those will be presented in this report. The results of the remaining tests will be presented at a later date.

To reduce the time required for data reduction, three separate computer programs were written, checked out, and used for the data to be presented in this report. They are used in conjunction with a recently installed terminal computer. A brief description of the computerized calculations will be made in the following report sections.

The one vacuum seal used in the test fixture has been modified from the Indium gasket type to one incorporating a copper gasket between spring loaded knife edges. The modified seal will be described in this report.

3.2 Leakage Tests and Results

3.2.1 General

In all of the tests made or to be made, the surfaces of the mating parts are a critical consideration. To be uniform for comparative purposes with surfaces used in the room temperature tests (Phase I) already reported on in final report Vol. 3, "Sealing Action at the Seal Interface", similar fabrication procedures were used. Talysurf profilometer techniques were employed as a means of evaluating the surfaces. The definitions of the surfaces made in Vol. 3 apply here, as well. Figures 3.1 through 3.4 are typical Talysurf representations of some of the surfaces presently being used in this program. Rather than attempt to match RMS or CLA numbers, visual observation of the traces taken over representative parts of the surface were viewed and judged as to uniformity of pattern and even height of asperities. Each surface was fabricated with a wedge shaped tool whose angle is determined by the surface required and the material. All surfaces, except those of the gaskets, were machined as circumferential asperities, without a lead. The gaskets were made with a 0.001 inch lead for each revolution of the gasket.

Figure 3.1 is a typical fine machined surface (FM). This is the surface that existed on the 2024-T4 aluminum seal piece prior to test 13. For all Talysurf traces, the long or horizontal scale is fixed at 0.002 inch per division as shown, the short or vertical scale being a variable, depending on the machine selector knob. In this case, it is 50 microinches per division. The profile can be seen to be very uniform and almost perfectly wedge shaped. The peak-to-peak dimension is an average of 450 microinches, comparable to that used for the Phase I tests in the past.

Figure 3.2 is a typical coarse machined surface (CM). It is the surface of the upper seal piece prior to test 8. The material is type 347 stainless steel. In this case, the vertical scale is 0.0001 inch as indicated. Again, uniformity is observed for the asperity distribution.

Figure 3.3 is a representative sample trace of a radially ground surface. This surface deviates considerably from radially ground surfaces depicted in the Vol. 3 final report. These asperities show up as a more random pattern as opposed to the regular pattern derived in the past. The trace here is taken in a line perpendicular to a radius line. The asperities run in an almost radial direction, so that the trace is taken nearly perpendicular to them. This trace was made prior to test 10 on the upper 347 stainless steel seal surface.

Figure 3.4 depicts the Talysurf trace of the gasket prior to use in test 10. This surface is machined with a lead of 0.001 inch per revolution. In this case, the material is 1100-0 aluminum.

The physical dimensions of the gaskets used for each test were:

$$\text{O.D.} = 1.1875 \pm 0.0005$$

$$\text{I.D.} = 0.9375 \pm 0.0005$$

$$\text{Thickness} = 0.060 \pm 0.001$$

All of the metal to metal tests employ the high rise surfaces similar to that shown in Figure 3.5. The O.D. and I.D. dimensions are the same as for the gaskets used.

For each test, a Talysurf trace is made of the seal surfaces prior to and after each test. A gasket profile, when one is used, is also taken before and after each test. Scratch marks are made on the seal surfaces prior to a gasket test so that an impression is made in the gasket as a reference for micorscopic examination of the surfaces after each test. Marks are made near the center of the gasket area and near the outer or inner edge. Each mark is small in relation to the width of the gasket and does not cloud the test results in any way.

Load-deformation tests are made following each gasket test on an identical gasket. From this data, the normalizing yield stress for the leak versus normal stress curves is obtained. A typical plot of this data is seen in Figures 3.6 and 3.7. The first figure is a plot of the hydraulic ram load (called net load) versus the average change in gasket thickness. The average change in thickness

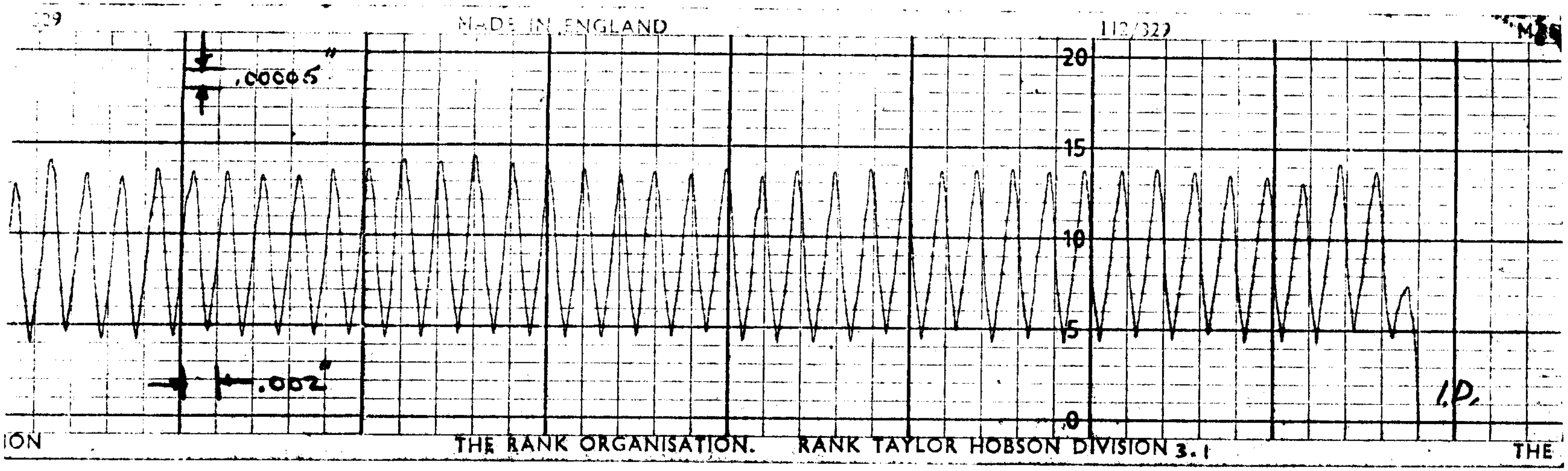


Figure 3. 1. Typical Fine Machined (FM) Surface.

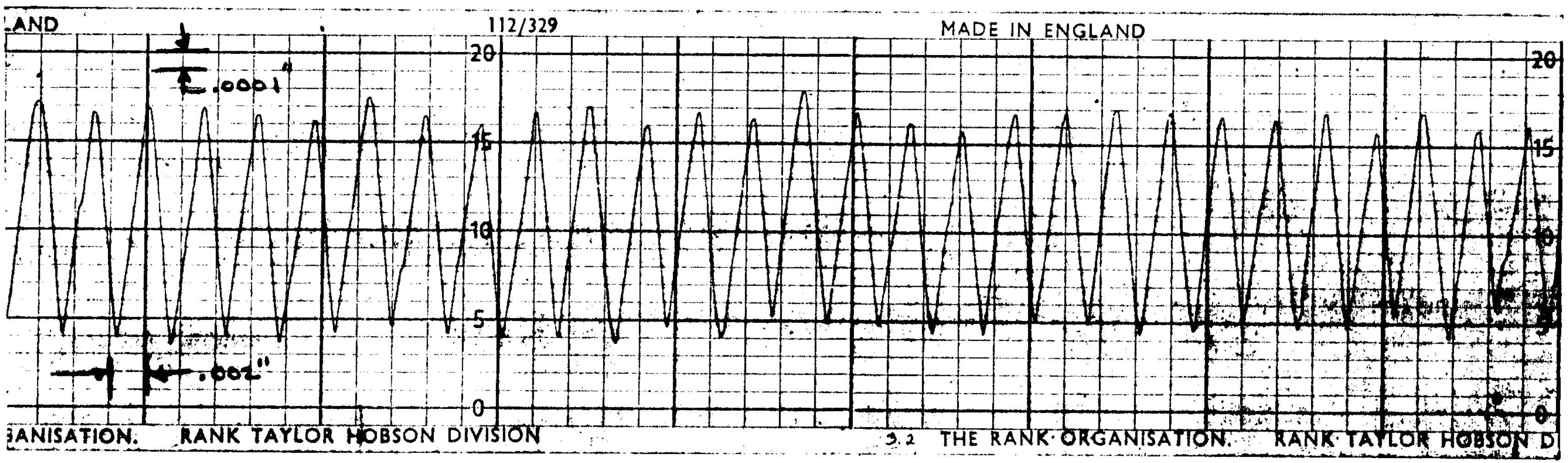


Figure 3. 2. Typical Coarse Machined (CM) Surface.

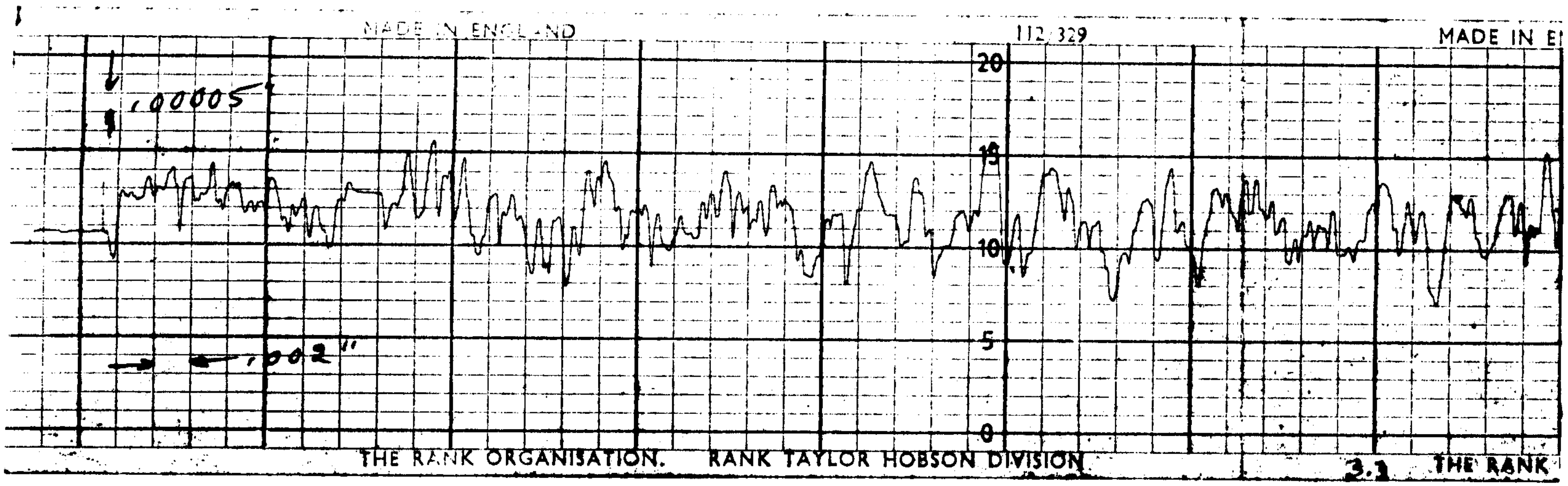


Figure 3. 3. Typical Radially Ground Surface.

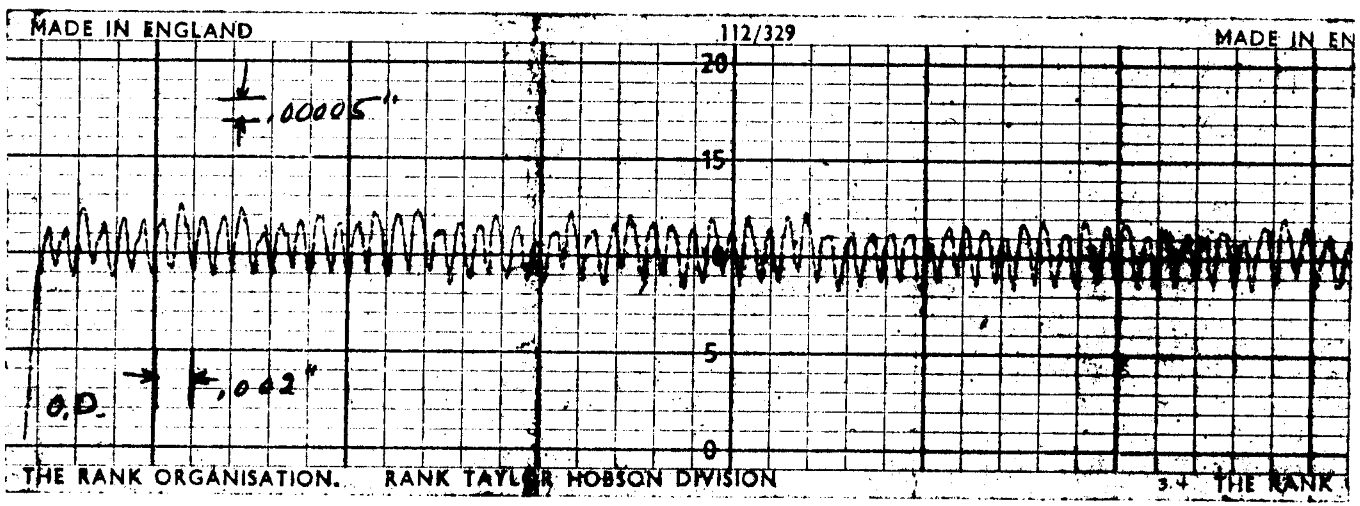


Figure 3. 4. Typical Gasket Surface.

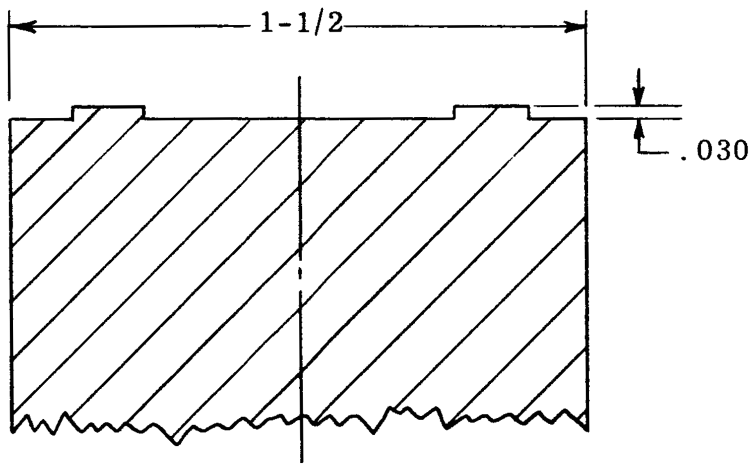


Figure 3. 5. Metal-to-Metal Test Seal Geometry.

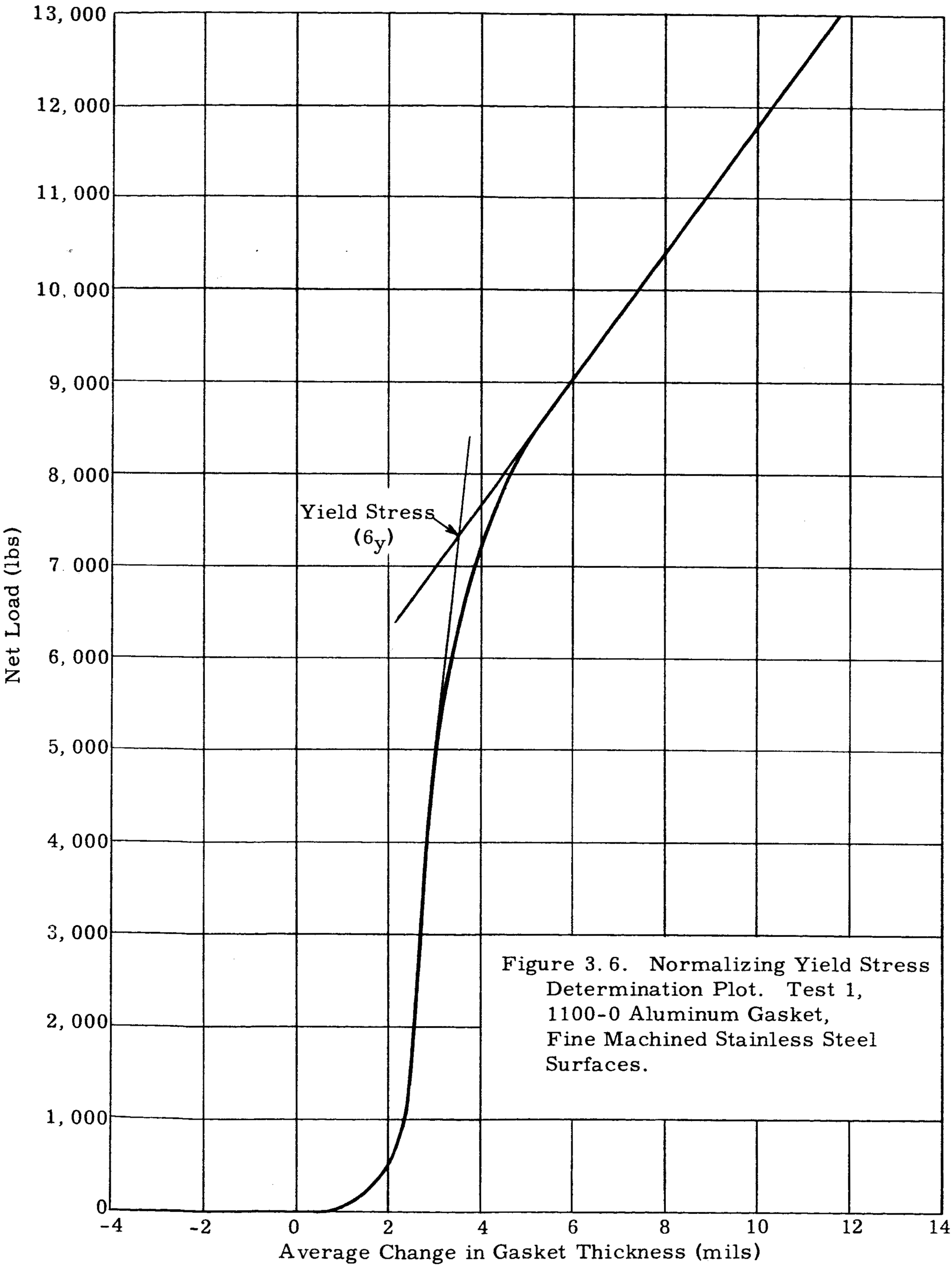


Figure 3. 6. Normalizing Yield Stress Determination Plot. Test 1, 1100-0 Aluminum Gasket, Fine Machined Stainless Steel Surfaces.

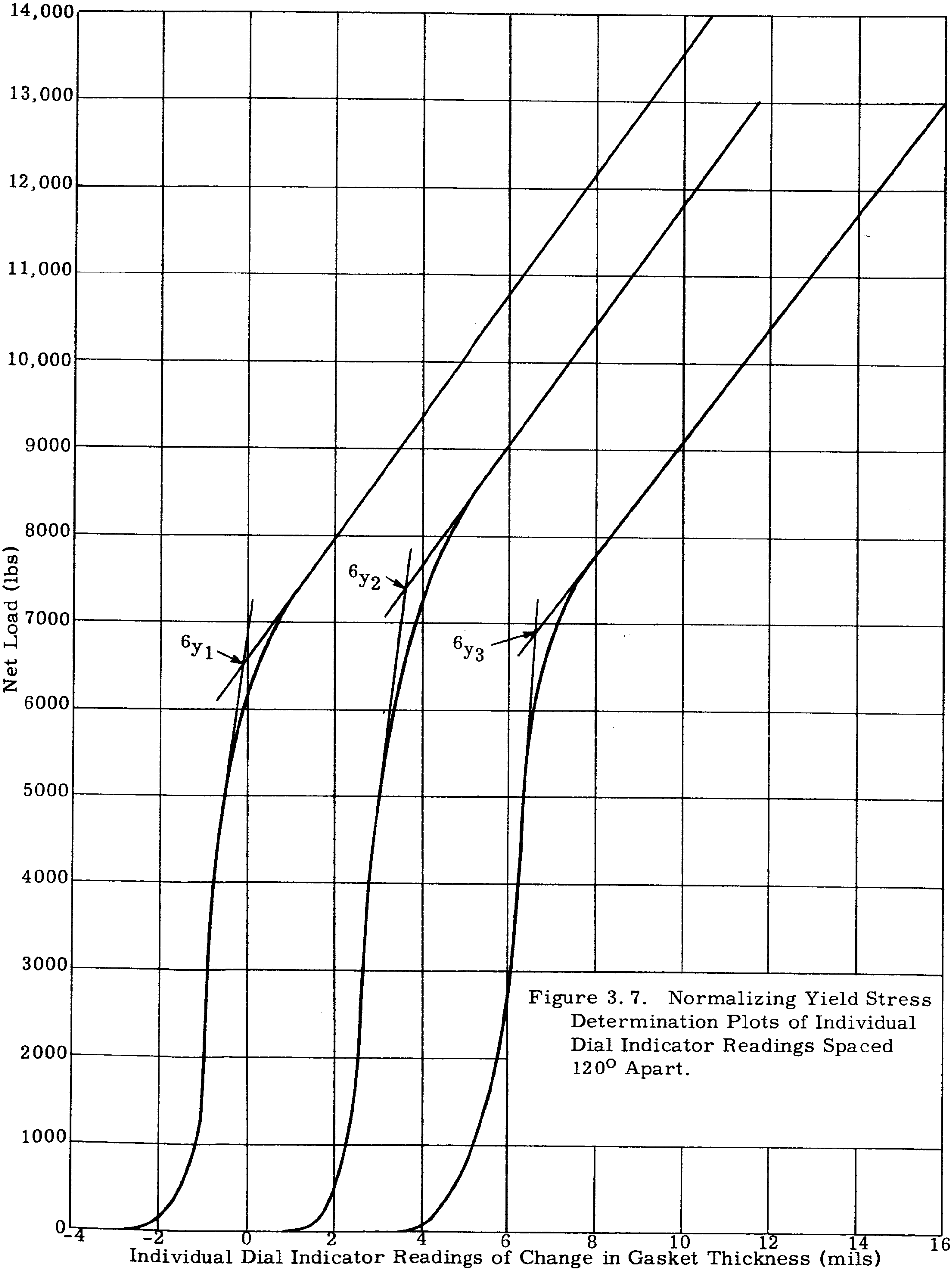


Figure 3. 7. Normalizing Yield Stress Determination Plots of Individual Dial Indicator Readings Spaced 120° Apart.

DATA FOR FIGURES 3.6 and 3.7

ALUMINUM GASKET

11-4-65
POST TEST
I.D. - 0.9108"
O.D. - 1.2140"
T. - 0.048"

LOAD POUNDS	GAGE #1 MILLS	GAGE #2 MILLS	GAGE #3 MILLS	Avg. (Δt)
0	0.36	0.33	0.41	0.37
100	- 2.13	2.70	4.13	1.57
200	- 2.90	2.75	4.28	1.38
300	- 1.74	2.85	4.40	1.83
400	- 1.67	2.91	4.51	1.91
500	- 1.58	2.94	4.62	1.99
700	- 1.42	2.94	4.82	2.11
1000	- 1.14	2.87	5.30	2.34
1500	- 1.11	2.79	5.60	2.42
2000	- 1.10	2.80	5.75	2.48
2500	- 1.05	2.80	5.85	2.53
3000	- 1.00	2.83	5.93	2.58
3500	- 0.89	2.92	6.05	2.69
4000	- 0.79	2.98	6.15	2.78
4500	- 0.65	3.12	6.25	2.90
5000	- 0.51	3.21	6.35	3.01
5500	- 0.21	3.27	6.49	3.25
6000	- 0.07	3.33	6.67	3.31
6500	0.28	3.39	6.90	3.52
7000	0.69	3.46	7.21	3.78
7500	1.25	3.55	7.63	4.14
8000	1.89	3.72	8.23	4.61
8500	2.58	4.00	9.00	5.19
9000	3.29	4.40	9.80	5.83
9500	4.05	4.93	10.60	6.52
10000	4.85	5.53	11.46	7.28
10500	5.59	6.13	12.20	7.97
11000	6.39	6.88	12.95	8.74
11500	6.97	7.76	13.62	9.45
12000	7.88	8.72	14.53	10.37
12500	8.37	9.21	15.00	10.86
13000	9.23	10.00	15.80	11.67
13500	9.88	10.65	16.44	12.32
14000	10.32	11.06	16.87	12.75
14500	10.98	11.73	17.57	13.43
15000	11.52	12.33	18.15	14.00

is the arithmetic average of the three dial indicators (spaced 120 degrees apart) used for this measurement. Figure 3.7 shows the individual dial indicator plots. Normally, the average curve would be used to attain the yield stress required, if the curve is as well defined as it is here. However, individual yield stresses were obtained, in this case, for each dial indicator. By comparison, the yield stress using the average curve was 16,340 psi as opposed to the average of the three readings of 16,570 psi. This represents very close agreement. The average curve is used for data reduction to define the overall change in gasket dimensions.

As pointed out in previous tests as reported on in Vol. 3 final report, the yield stress as determined in this manner is more indicative of the yield phenomenon as applies to the configurations and surface finishes used. The figures as determined in this manner will be used for this series of tests as normalizing gasket stresses throughout.

3.2.2 Data Reduction Programs

To reduce data more efficiently, several computer programs were written for use with the terminal computer installation at our plant.

The first is the basic averaging of the three individual dial indicator readings used in yield stress determination.

The second deals with corrections applied to the leak detector current readings. Each scale of the amplifier requires a different correction, however slight. Normal manual procedure is to take a current reading, search the range of scales versus correction factors, pick the proper correction, and multiply to get a corrected reading. This procedure has been simplified by the computer program to the extent of requiring all data current readings to be entered as a sample of data lines with the computer output being the corrected readings.

The third program is the conversion from corrected leak detector current readings to leak rates. In manual reduction, each current value is matched to a leak value by entering the leak detector calibration curve. Since the calibration curve is a straight line on a log-log plot, it is an exponential function which results in a simple computer program. Use of it requires entering of the slope of the calibration curve and its intercept plus the various corrected leak detector current readings.

3.2.3 Test Results

To avoid confusion, the test numbers to be related are the same as those used in Table 3.1 of the previous monthly report (October 15, 1965). In that report, two tests' results were presented and labelled #1M and #3M. Since unusual results for each test were achieved, those tests were re-run and from now on will be classed as the Table 3.1 numbers of 1 and 13.

Test #1 (Figure 3.8)

This test incorporated fine machined (FM) stainless steel seal surfaces, type 347, with an 1100-0 aluminum gasket. Figure 3.8 is a plot of the leak rate versus the normalized gasket stress. Phase I can be seen to take a jog which increased the leakage after starting with a lower value. This is most likely due to the seating of the gasket during load application. Beyond this change, however, Phase I proceeds in normal fashion. No Phase II was evidenced. An increase in internal pressure to 6000 psi did not result in increased leakage once the 14.7 psi differential pressure leak was quelled. This is an indication of the good sealability derived from the softer gasket materials like the soft aluminum used in this test.

At the end of Phase I the applied stress was kept constant with 6000 psi internal pressure and the seal combination temperature cycled first to -321^{o}F and then to +250^{o}F (the temperature at which the yield strength of 1100-0 aluminum reduced to 80 percent of its room temperature value). For this test, no change in leak level was observed.

Phase IV was accomplished at +250^{o}F and resulted in the curve shown. No leakage was noted until the stress was reduced to 0.28 times the yield stress. At this time a catostraphic release of the 6000 psi helium internal pressure was witnessed. As a result of this, the gasket was fractured and post test measurements could not be made. The large reduction in normal stress before leakage resulted is typical of the soft gasket type of seal and illustrates the insensitivity of it to load reduction.

Tests #2, #6, and #7

All of these tests were made with soft plastic or rubber gaskets. Sealing was observed by application of the vacuum test fixture. This results in a 72 pound force being applied to the gasket surface area. The stress then becomes approximately 175 psi. Since efforts in past tests which employed the soft gaskets resulted in catastrophic results when the internal pressure was increased, these gaskets were tested with an atmosphere of pressure differential with only the vacuum force being exerted as a normal load on the gasket. In this situation, the seal was subjected to the liquid nitrogen test and leakage recorded for comparative purposes. All of these tests were made using fine machined type 347 stainless steel seal pieces.

Test #2 employed a silicone rubber gasket. With the vacuum force applied and 14.7 psi internal pressure, the leakage was about 1.8 x 10^{-6} atm cc/sec. For this test only, a small load was applied to determine its effect on leakage.

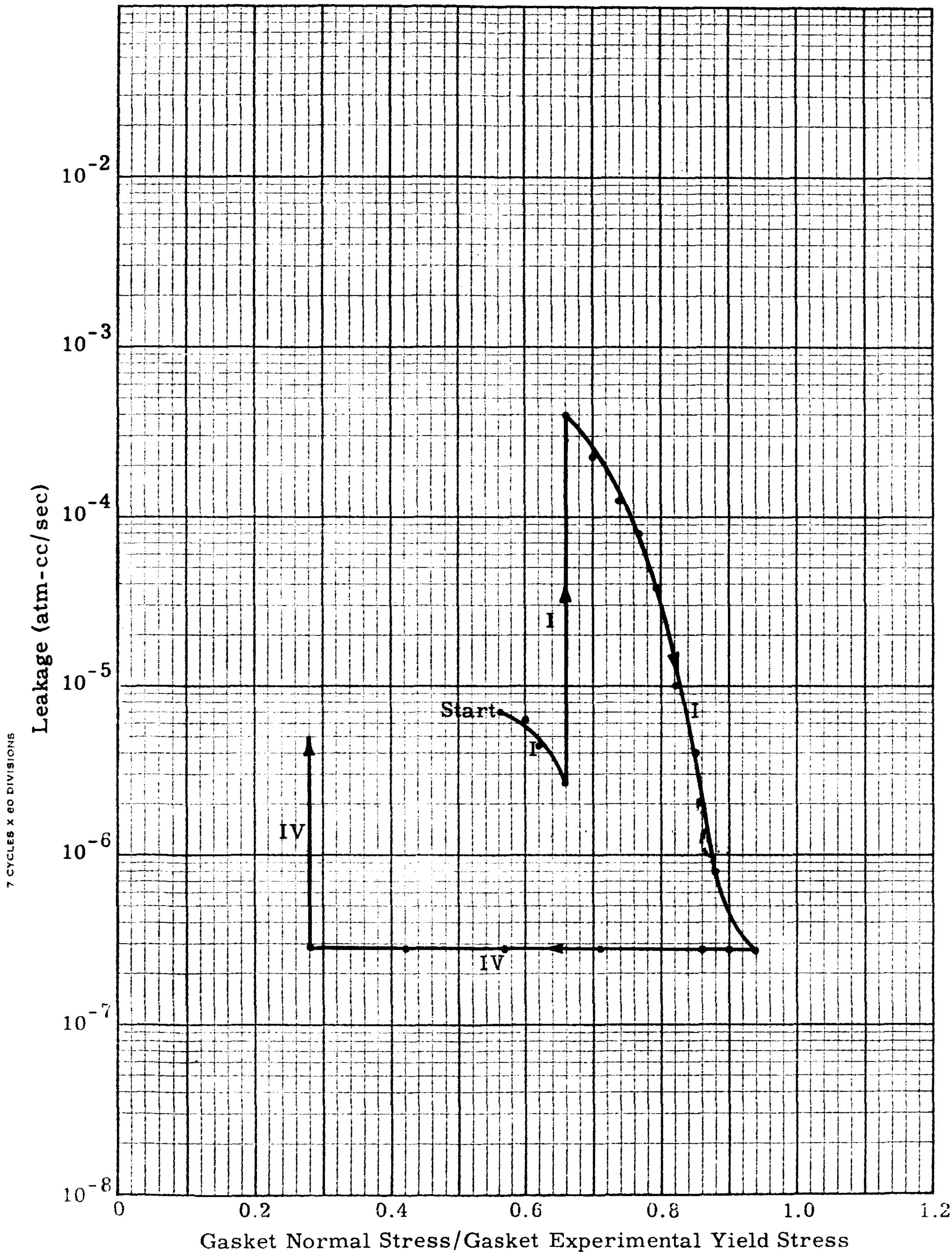


Figure 3. [illegible]. Test 1 - Fine Machined 347 Stainless Steel Seal Surfaces with 1100-0 Aluminum Gasket.

With 200 pounds external hydraulic ram load, the leakage was approximately the same at 1.4×10^{-6} atm cc/sec. At this point, the liquid nitrogen test was begun and as the temperature of the seal pieces was reduced, the leakage increased. With the final temperature stabilized, the leakage was 1.4×10^{-3} atm cc/sec with 200 pounds external force and 9×10^{-3} atm cc/sec with one atmosphere pressure differential.

Test #6 was one made with a Viton A gasket. With a vacuum force applied to the gasket, a zero leak resulted (about 4.5×10^{-7} atm cc/sec). With the immersion of the test fixture in liquid nitrogen, leakage began 13 minutes after the start of the cold test. Excessive leakage, high enough to trip the leak detector safety device, was observed at the temperature stabilization point.

Test #7 was made using a neoprene rubber gasket. Zero leakage (about 5×10^{-7} atm cc/sec) resulted with the application of the load to the gasket. Again, leakage increased during the low temperature test until it was about 1.2×10^{-2} atm cc/sec at the stabilized low temperature.

Tests #4 and #5 (Figures 3.9 and 3.10)

Both of these tests were made with the same fine machined stainless seal pieces as used for the other plastic and rubber gasket tests. These tests were made using FEP and TFE teflon gaskets. Separate prior tests were made to determine the maximum pressure each could withstand without failure in a radially unsupported manner. Tests #4 and #5 were made at a slightly lower pressure. The gasket as used in this manner, then, is operating under very severe seal conditions. Both teflons reacted in a similar manner. Sealing down to 10^{-6} atm cc/sec at a one atmosphere pressure differential occurred during Phase I. Application of internal pressure at constant stress (Phase II) resulted in about the same leak in both cases (3.5×10^{-4} atm cc/sec) although the FEP gasket internal pressure was 2200 psi and that of the TFE 1500 psi. Efforts to reduce this leakage (Phase III) were not successful, resulting in very little reduction even though high seal loads were applied.

Application of liquid nitrogen resulted in better sealability, down to the level of room temperature leakage at one atmosphere pressure differential.

Phase IV illustrates the degree of sensitivity of the seal system to load removal, this phase being carried out at the -321°F temperature.

Test #10 (Figure 3.11)

Figure 3.11 is the plot of data derived from the test of the radially ground 347 stainless steel seal pieces and an 1100-0 aluminum gasket. Phases I, II and III were accomplished as shown. At the end of Phase III, the liquid

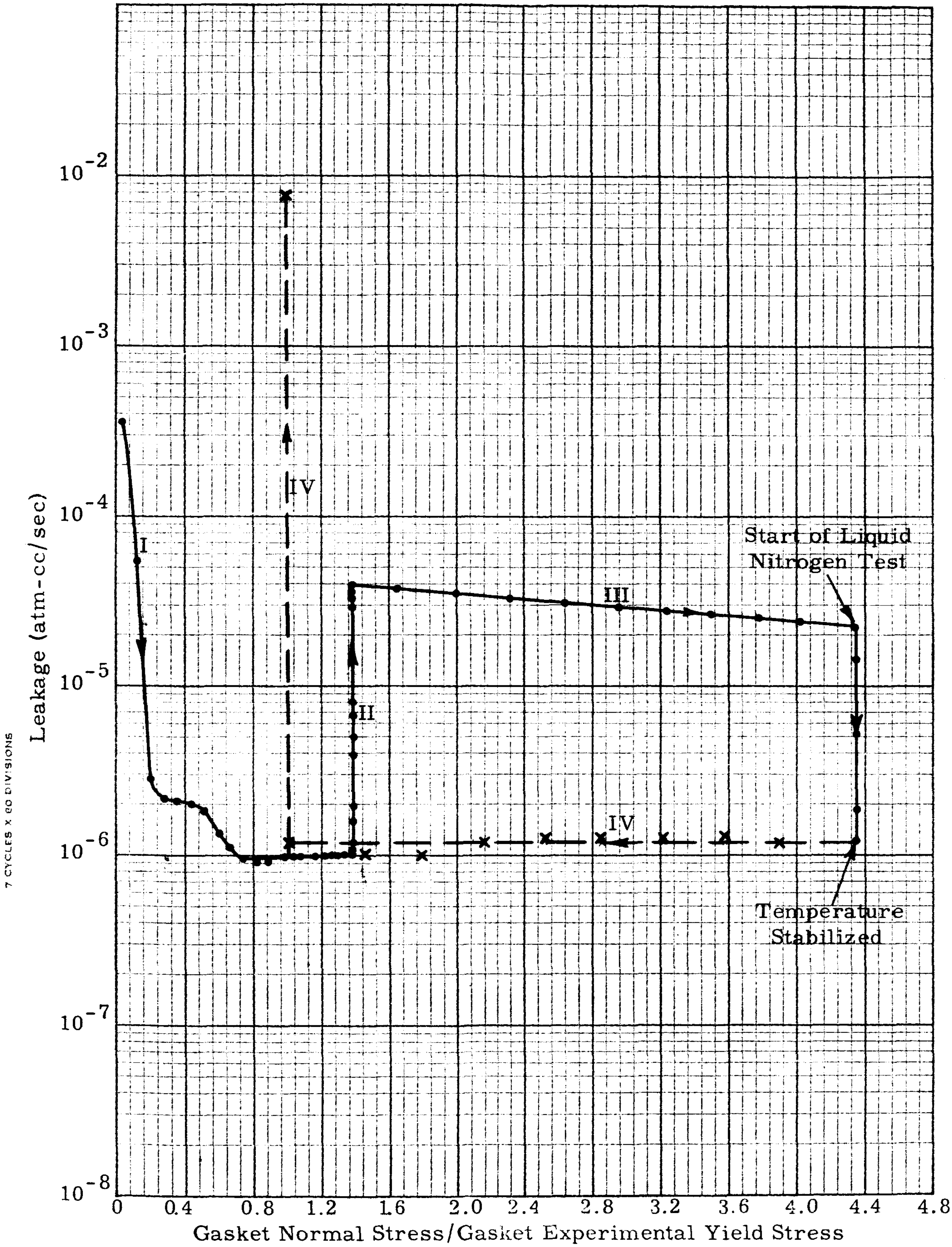


Figure 3.9. Test 4 - Fine Machined Stainless Steel Surfaces with Teflon FEP Gasket.

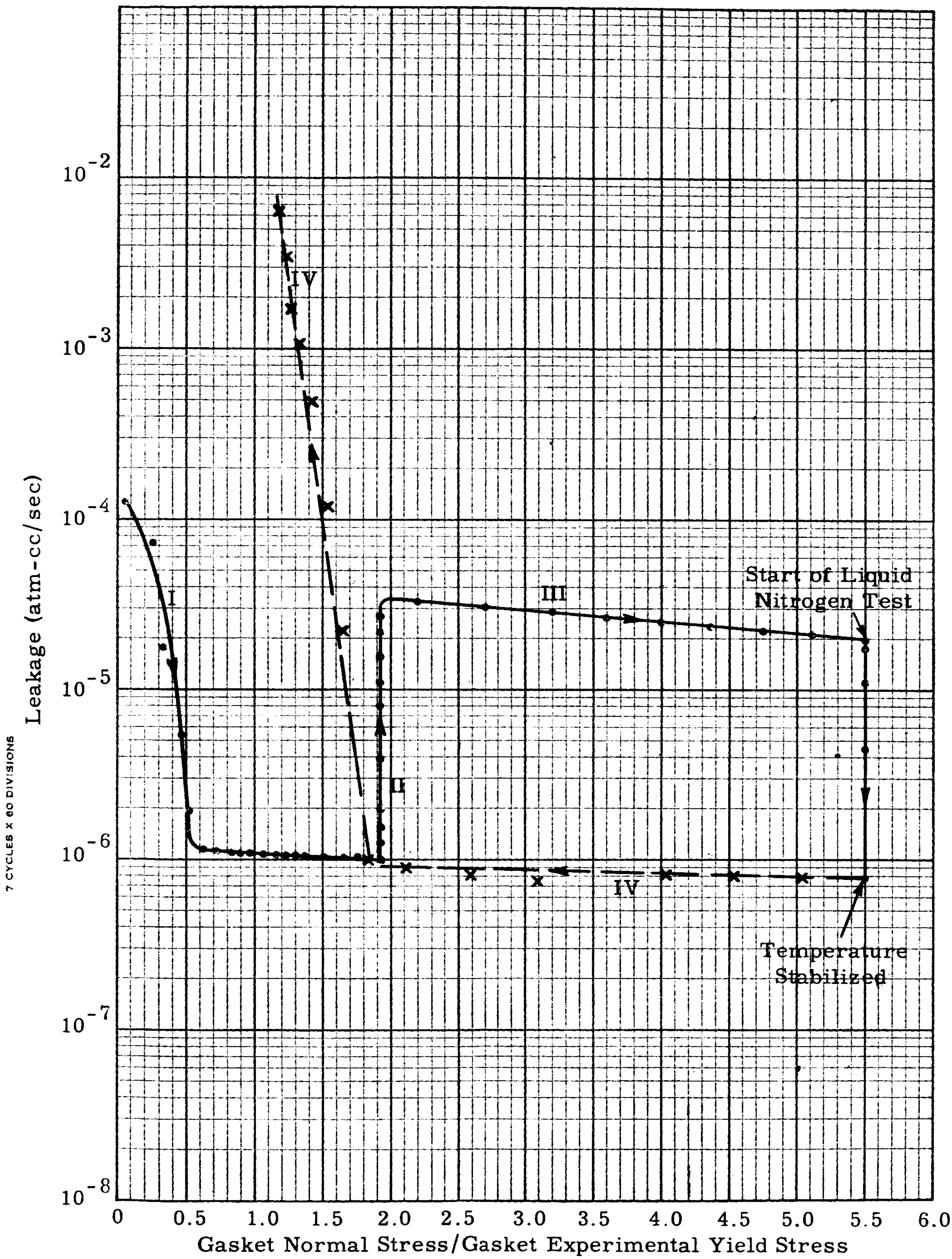


Figure 3.10. Test 5 - Fine Machined 347 Stainless Steel with Teflon TFE Gasket.

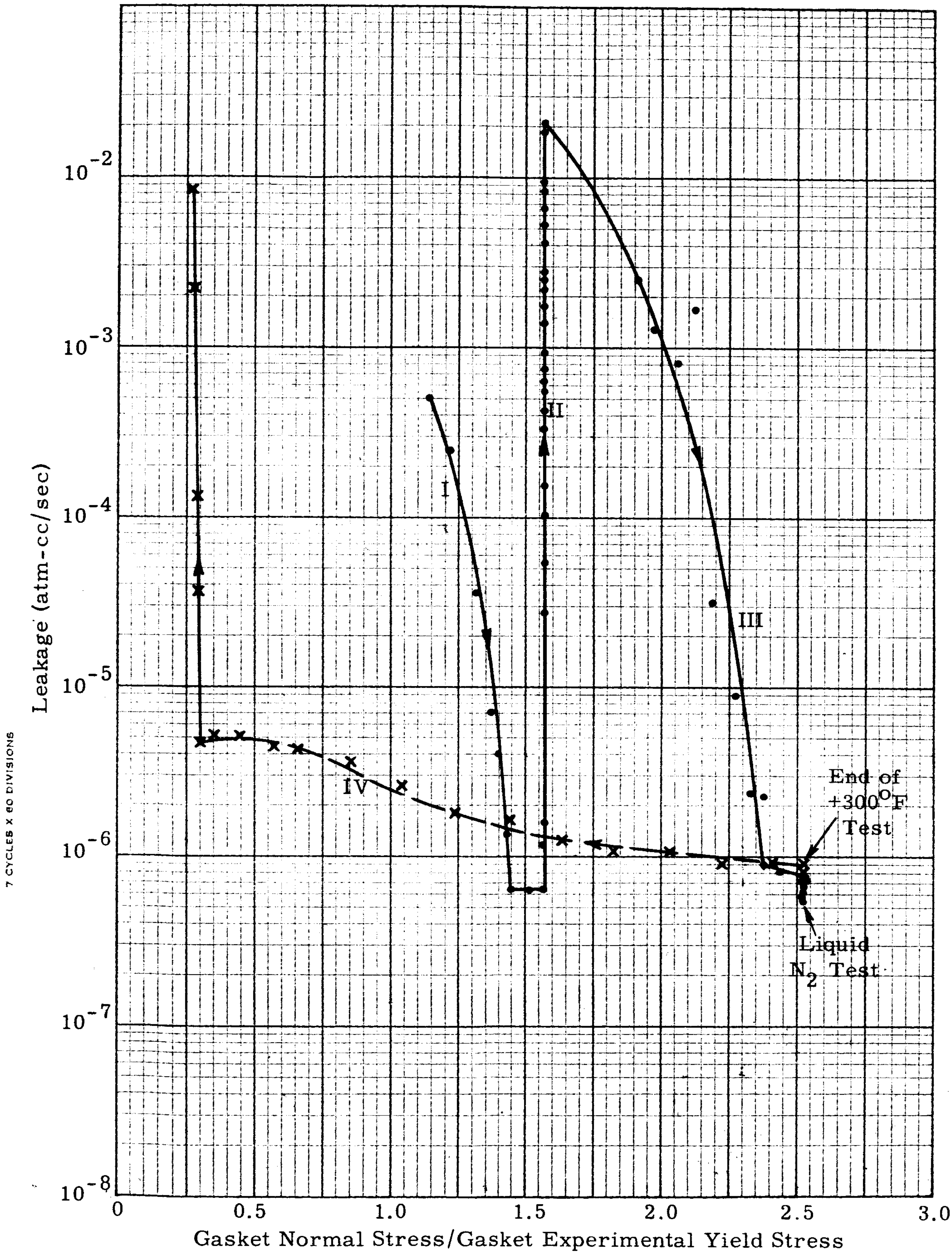


Figure 3.11. Test 10 - Radially Ground 347 Stainless Steel Seal Pieces with an 1100-0 Aluminum Gasket.

nitrogen test (-321°F) showed little change in leakage. The hot test was accomplished this time at +300°F with a small increase in leakage from 5.6×10^{-6} atm cc/sec before the test to 9.2×10^{-6} atm cc/sec at the end of the test.

Phase IV resulted in the curve shown, the soft gasket sealability again exhibiting the degree of sensitivity to load removal as shown.

Test #11 (Figure 3.12)

This test employed radially ground stainless steel surfaces with a copper gasket. All phases showed very good regularity. Some small changes in leakage during the cold and hot (+400°F) tests were noted, the hot test leakage being slightly greater than that at the low temperature. The degree of sensitivity to load removal is noted for this system, with Phase IV, the load removal, accomplished with the system at the high temperature.

Test #13 (Figure 3.13)

This test was a metal to metal test without a gasket. Both seal surfaces were in high relief as described earlier. In this case, the normalizing stress was the 0.2 percent yield stress of the weaker material, the type 347 stainless steel. Aluminum, type 2024-T4, was used as the other seal piece, with both seals using a fine machined surface.

Zero leakage was observed during Phase I at a normalized stress ratio of 1. Phase II resulted in a maximum leak rate of 1.6×10^{-2} atm cc/sec. The corresponding Phase III required a stress level of about 1.7 to reduce this leakage to the zero leak requirement. The hot and cold tests showed a very slight change in leak rate, the leakage increasing slightly during the +300°F test. The maximum operating test temperature for this test was determined by the aluminum sample whose yield strength is reduced to 80 percent of its room temperature value at 300°F. Phase IV shows the degree of sensitivity of this system to load removal, its leakage beginning to increase at about 0.4 times the normalizing yield stress.

Test #14 (Figure 3.14)

This test shows a very high degree of data scatter beyond Phase II. The curves drawn for Phases III and IV are best estimates of the presented points. A great variation in leak rate was observed during the hot and cold tests following Phase III. This test employed fine machined 6061-T6 aluminum seal surfaces with an 1100-0 aluminum gasket. To better define the estimated phases, it is planned to re-run this test.

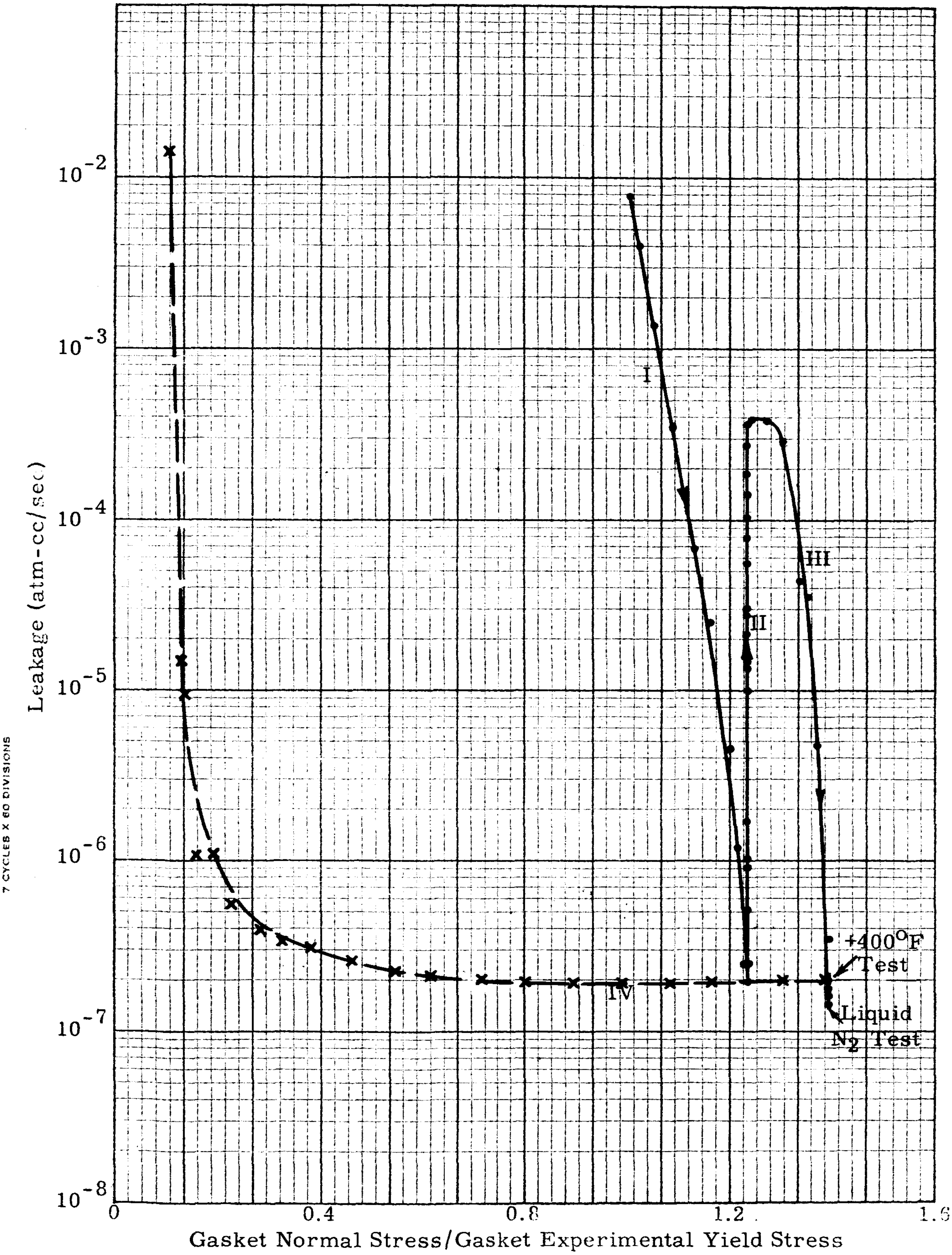


Figure 3.12. Test 11 - Radially Ground 347 Stainless Steel Seal Surfaces with Copper Gasket.

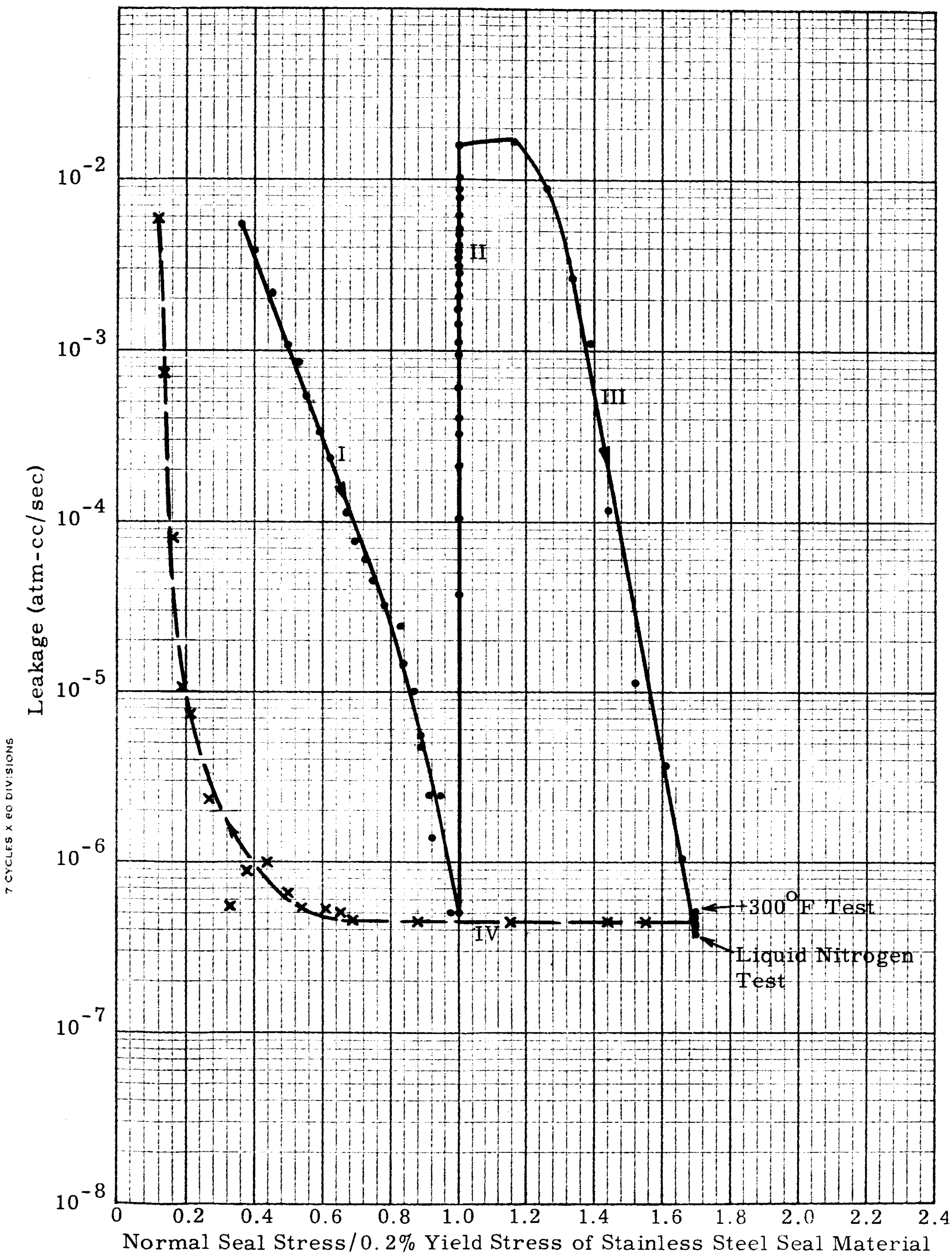


Figure 3.13. Test 13 - Fine Machined 347 Stainless Steel with 2024-T4 Aluminum - Both Surfaces at High Relief - No Gasket.

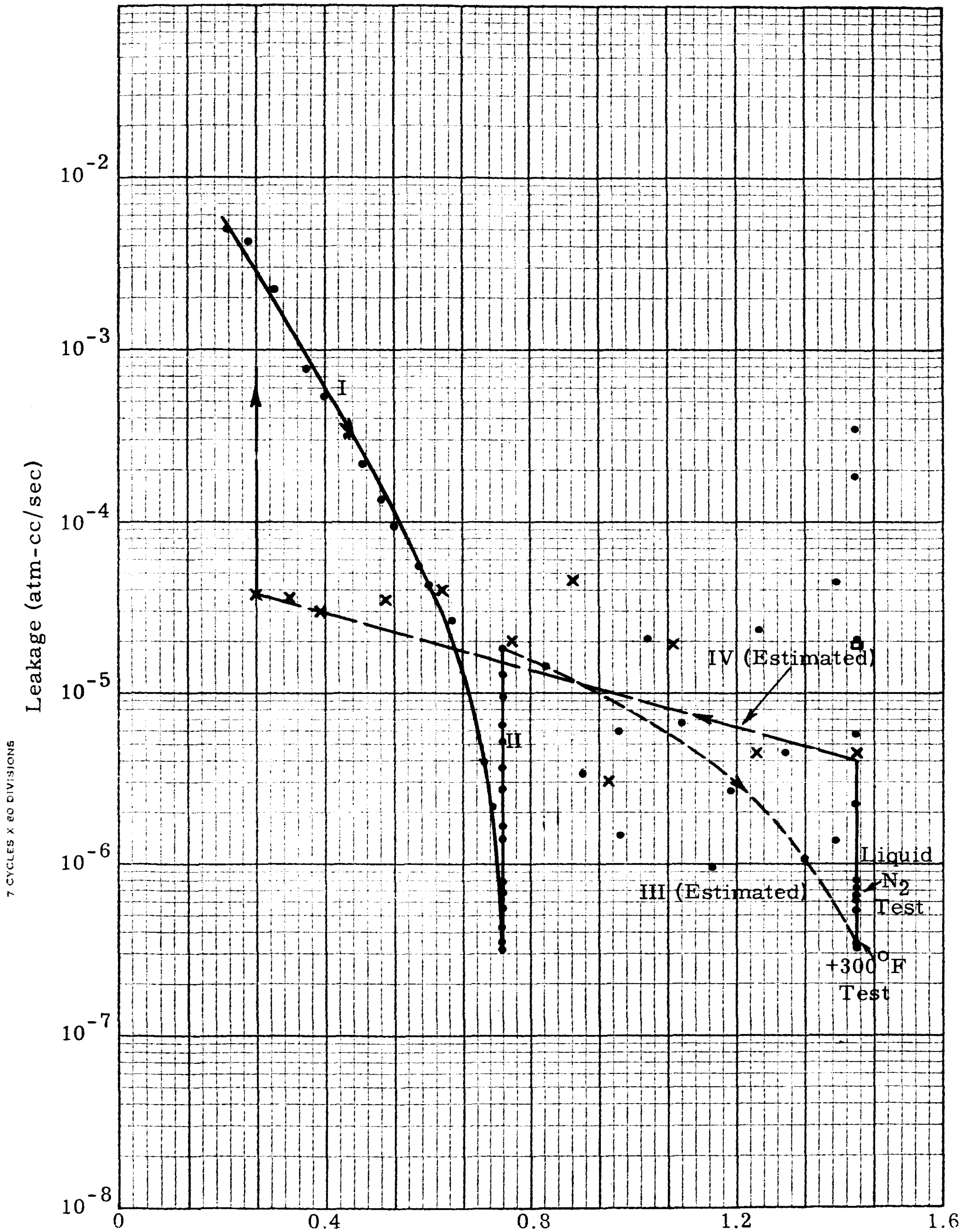


Figure 3. 14. Test 14 - Fine Machined 6061-T6 Aluminum Seals with 1100-0 Aluminum Gasket.

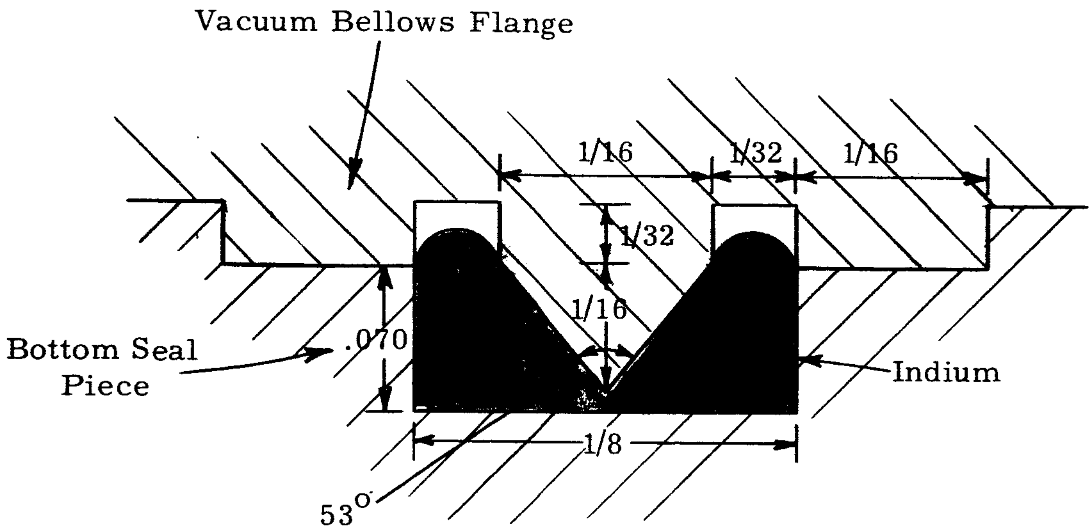
Test #12

An attempt was made to perform this test. It was unsuccessful, however, in that the Phase II leakage could not be quelled within the capacity of the load machine (60,000 pounds of force).

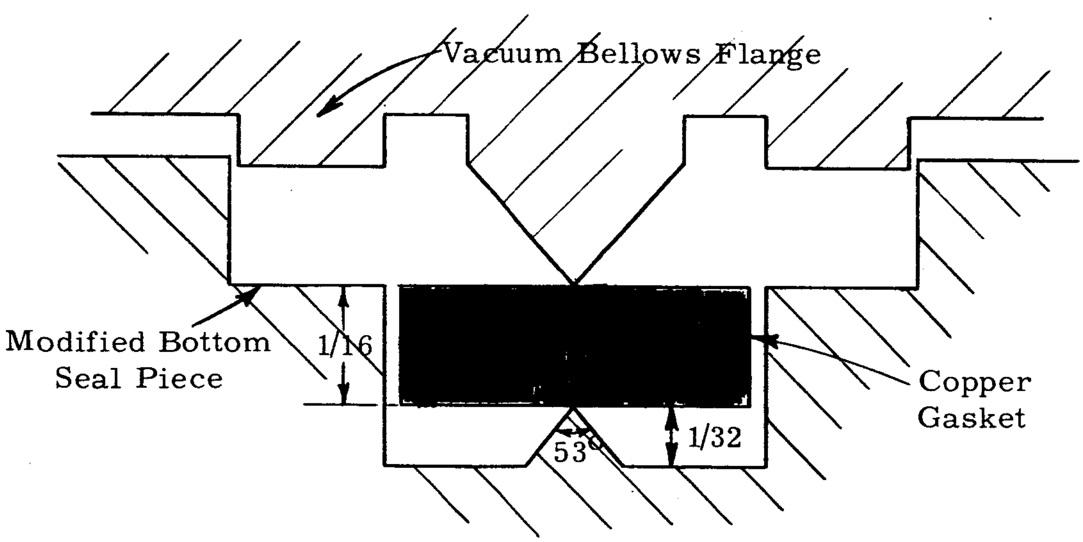
Figure 3.15, top, shows the original indium gasket seal used between the bellows flange part and the lower seal piece. As mentioned before, leakage was observed for this seal at the low temperatures. The lower part of the figure shows the seal presently used and the modified lower seal piece. Each bolt that holds the two parts together has a spring washer underneath its head. They provide a force at the knife edges high enough to maintain a vacuum seal throughout all the temperature excursions.

3.3 Future Work

In the future, efforts will be made to carry on with the proposed test program. Also, when more data is derived and reduced, more definite conclusions will be made concerning the seal systems and their action as a function of the imposed conditions.



Former Indium Gasket Seal



Spring Loaded Knife Edge Seal

Figure 3.15. Modification of Indium Gasket Seal to Spring Loaded Knife Edge Seal.

4. Tube Connector Utilizing Superfinished Sealing Principle

4.1 Summary and Conclusions

4.1.1 Introduction

The purpose of this task is to design, manufacture and test a threaded connector for 3/4 inch tubing, utilizing the superfinished surface sealing principle. During the last quarter, work has proceeded along five lines which are briefly summarized in 4.1.2 through 4.1.6 and further discussed in the following paragraphs.

4.1.2 General Design and Manufacturing Outline

From tests which were described in the last quarterly report, several decisions have been made:

a) The connector is being designed for 6000 psi internal pressure.

b) Connector material is fully hardened A-286,

c) Connector and tubing will be joined through Electron Beam (EB) welding.

d) A manufacturing sequence including machining, heat treatments, superfinishing and assembly had been determined.

4.1.3 Optimization of Major Connector Dimensions

This subtask is currently being done using the design procedure in the Separable Connector Design Handbook. It will be discussed in detail when finished.

4.1.4 Design of Seal Interface Area

The design procedure according to 4.1.3 gives the major connector dimensions, but no details about the seal interface and surrounding area. The seal area design, including means for alignment during assembly and seal protection, has separately been reviewed for proper functioning and simplicity during manufacturing. A tentative solution is presented.

4.1.5 Electron Beam Weld Test

One EB-weld between a flange of fully hardened A-286 and 316 stainless steel tubing has been leak tested to 1,000 psi and fracture tested to 15,000 psi. The test showed no leakage or fracture.

Test samples for optimization of the EB-weld procedure are currently being manufactured.

4.1.6 Leakage Test for Superfinished Surfaces on A-286

No leakage tests have yet been made for:

a) superfinished surfaces made of A-286, fully hardened

b) the design pressure 6000 psi (highest previous test pressure = 2000 psi)

Therefore, test samples, intended for such tests, have been manufactured. Superfinishing remains before the tests can be performed.

4.2 General Design and Manufacturing Outline

4.2.1 Design Pressure

In the last quarterly report it was discussed whether a design pressure of 4000 or 6000 psi should be chosen. The original design pressure was 6000 psi but early studies showed that, if the connector were to be made of a regular stainless steel, a secondary load path would be required. Later the secondary load path design was ruled out because of manufacturing difficulties. Therefore, it was concluded that the connector must either be made of a superalloy, or the design pressure reduced.

Since then experiments with EB-welds of fully hardened A-286 alloy have indicated that the use of a superalloy is feasible. Therefore, we see no longer any reason for reduction of the design pressure. The connector is conclusively being designed for 6000 psi internal pressure.

4.2.2 Material Choice

Connector material is fully hardened A-286, a precipitation hardening stainless steel with high nickel content. Its properties have been discussed in the two previous quarterly reports. A-286 is, through EB-welding, compatible with most tubing materials.

4.2.3 Connector - Tubing Weld

Experiments with EB-welding has shown that it is possible to weld a connector made of hardened A-286 to the tubing without producing significant cracks or warping the seal surface. This also means that superfinishing can be done after hardening, and the problems with distortion of the seal surface during the hardening heat treatment disappear. EB-weld appears to be the only possible way to join connector and tubing unless an excessive connector length is chosen, and will therefore be used. Results of EB-weld pressure testing will be described later in this report.

4.2.4 Manufacturing Sequence

The following sequence will be used for manufacturing of the connectors.

a) Annealing of the raw materials if this is not done before delivery.

b) Rough machining. The material is easiest to machine when annealed but hardening changes the dimensions somewhat.

c) Hardening. 16 hours in 1325°F in vacuum. Vacuum cooling.

d) Machining to final dimensions.

e) Superfinishing of seal surfaces. This will be done by the Jones Optical Works.

f) Assembly of protection and alignment rings to the connector.

g) EB-welding of tubing to the connector.

h) Assembly of the connector.

4.3 Optimization of Major Connector Dimensions

This task is outlined in the Separable Connector Design Handbook. The work is currently being done and is planned to be finished within the next contract month. Results from work on Task I (computer studies), are partly being used.

4.4 Design of Seal Interface Area

A tentative design for means of protection of the seal surfaces and alignment during assembly is shown in Figure 4.1. It utilizes two or four split snap-rings which are permanently attached to the connector. In addition to providing protection and alignment they also keep the two connector halves pressed together with a slight preload before the nut is engaged.

The reason why the number of snap-rings, two or four, is not yet determined will be explained:

The two outer rings, which are actually shown in the figure, are necessary. They provide assembly alignment, initial preload, preload, and a reasonable degree of protection.

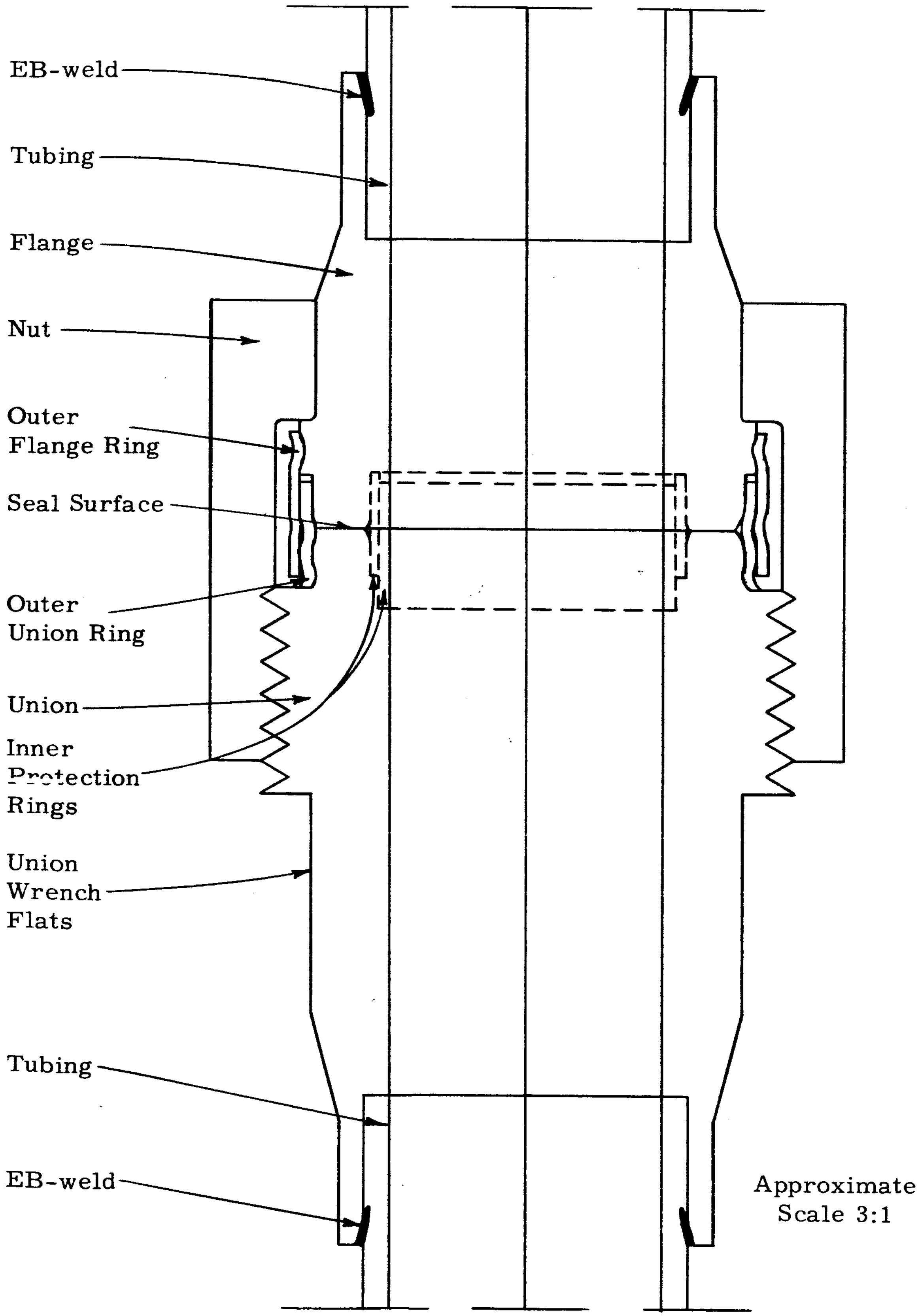


Figure 4.1. Tube Connector Utilizing Superfinished Surface Sealing Principle.

The two inner rings, only indicated by dotted lines, provide a higher degree of protection which is desirable but probably not an absolute requirement. Whether the two inner rings will be used or not will depend upon the final major connector dimensions, as determined in 4.3. We want to have a seal width of approximately 1/8 inch and a thickness of the snap-rings of at least 1/32 inch each. If the final dimensions (spec D_f, D_u, D_a, according to the Design Handbook) come out such that there is room for the two inner protection rings without increasing the major connector dimensions, they will be incorporated into the design. If there is no room, only the two outer rings will be used. In other words, we do not intend to over dimension the connector only to make room for the inner protection rings.

The attachment of the protection rings to the connector is not determined in detail yet. Figure 4.1 indicates grooves which the split rings snap into. Other means are shrink fit, spot weld, or EB-weld, but practical tests have to be made to determine risk for seal surface deformations.

It is our intent to choose as simple a protection means as possible, especially considering possibilities to achieve low cost during mass production.

4.5 <u>Electron Beam Weld Test</u>

The feasibility of using EB-weld for welding hardened A-286 was discussed in the previous quarterly report. At the time when that report was written, two EB-welds had been made seemingly with successful result. During the last quarter, one of the EB-welds has been pressure tested in two ways:

a) Leakage test with maximum pressure 1000 psi: this test was made with helium as pressurized medium and leakage was measured with mass spectrometer. No leakage could be detected.

b) Fracture test with maximum pressure 15,000 psi (2.5 times the design pressure): pressurized medium was oil.

Pressures up to 12,000 psi gave no visible change in flange, tubing or weld. Pressure 15,000 psi gave approximately 15 percent yielding of the 316 tubing, but the EB-weld did not fail. Considering that the yielding of the 316 tubing caused considerable deformation of the weld area it can be concluded that the 316 - A-286 EB-weld is ductile at room temperature.

The tested EB-weld before the test was shown in Figure 4.14a in the previous quarterly report. The weld after the pressure test is shown here in Figures 4.2 and 4.3.

After the pressure test, the weld was sectioned and etched for microscopic studies. Evaluation of this sample by experts has indicated that no significant cracks are present. The sectioned weld is shown in Figures 4.4 and 4.5.

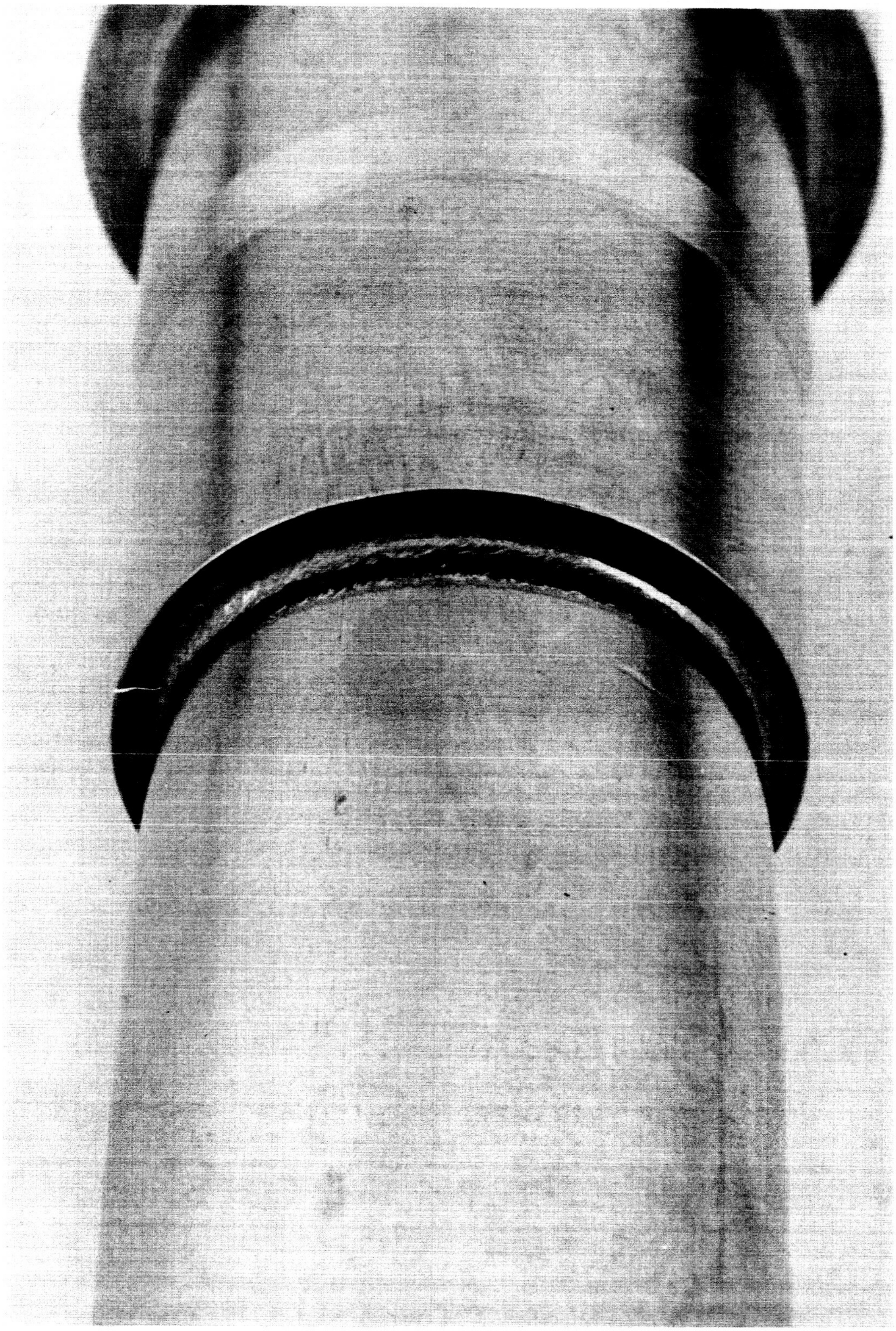


Figure 4.2. Electron Beam Weld after 15,000 psi pressure test.
(Compare Figure 4.14a in the previous Quarterly Report.)

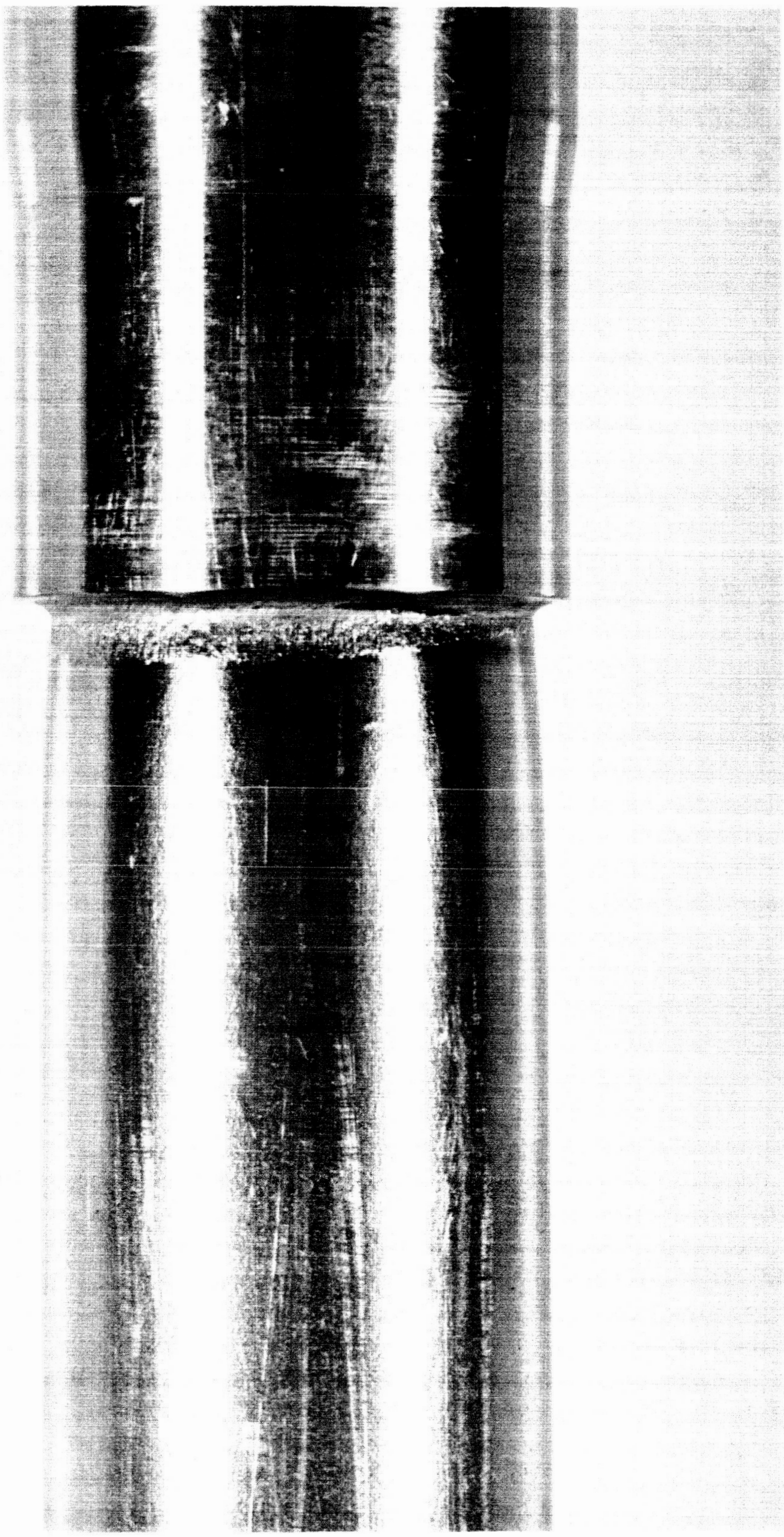


Figure 4.3. Electron Beam Weld after 15,000 psi pressure test.

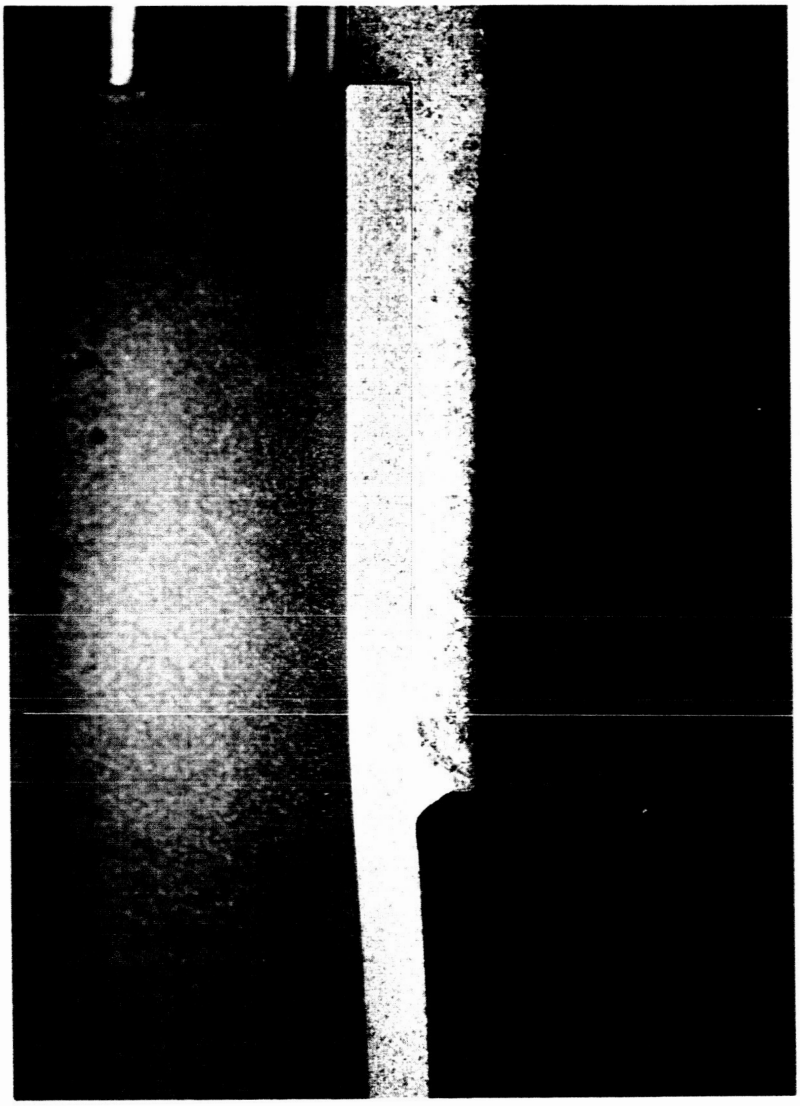


Figure 4.4. E. B. Weld test specimen after 15,000 psi pressure test.

Figure 4.5. E.B. Weld test specimen after 15,000 psi pressure test.

We are planning some further EB-weld tests to give us a more solid background for optimization of the weld procedure. Samples are currently being manufactured.

4.6 Leakage Tests for Superfinished Surfaces on A-286

Our previous experience with superfinished surface seal covers only regular stainless steel (347) and the pressure range 0 - 2,000 psi. It has earlier been concluded that the use of a hardened superalloy like A-286, should increase the allowable seal stress range considerably but no tests have been made yet.

Therefore, we plan to make a laboratory test, using the redesigned high pressure test fixture, to test the sealing properties of superfinished hardened A-286 with a 6000 psi pressure differential across the seal. The results of this test will:

a) Help to check that the right preload is used in the final design.

b) Give a well-defined leakage reference with which results of the actual connector leak tests can be compared.

Test specimens for the planned test have been manufactured and are currently being superfinished. The test will be finished within the next contract month.

4.7 Current Status of Work

According to our present plans, we will need one more month until the detailed connector design is available. Once this is achieved, manufacturing of the two first prototype connectors will start immediately.

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